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THE INTERNATIONAL CONFERENCE ON TITANIUM
LONDON, 21-24 MAY 1968

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Introduction

Titanium is no longer considered to be a panacea, as it was 10-15 years ago. At that time it was oversold and underdeveloped. In the meantime, a great deal of patient research and development have been accomplished and considerable new information is at hand.

Thus, it was with high expectations that more than 400 metallurgists--basic, applied, engineering, sales and executive--assembled at the International Conference on Titanium, held in the Purcell Room of the Royal Festival Hall, London, 21-24 May 1968. The meeting did not live up to our expectations, but not because of a lack of information available to be presented.

The organizing committee had chosen to use the rapporteur system for the Conference. The beauty in this system is that it allows the presentation of a great many papers in a given time without having to resort to the evil of simultaneous sessions. The success of the system, I believe, depends on two main factors: that the completed papers are printed and distributed to all preregistered attendees at least one month before the meeting (and that some of the attendees actually read the preprints, perhaps prepare a thoughtful written discussion, but at least think about the information before the meeting); that the rapporteur is himself an active leader in the area he has been chosen to summarize, that he is capable of extracting the essence from each paper, weaving it into a coherent story, criticizing where necessary and presenting thought provoking alternatives if possible. It goes without saying that the completed papers must be in the hands of the rapporteur at least 30 days prior to the meeting.

If these are the ingredients of a successful meeting using the rapporteur system then the flaws in the current meeting are easy to enumerate. The completed papers were not available to the attendees before or during the meeting; a one-page abstract of about 90% of the papers was available 15 days before the meeting. Some of these abstracts (especially those from Russia) were so general as to be useless. Thoughtful, prepared discussion was, thus, virtually impossible: Prior study by those not intimate with the whole of titanium metallurgy was made difficult. Thankfully, most of the rapporteurs were well chosen and did an excellent job. But, a few of them had not received completed papers by the time of the meeting; some had to ad-lib from the one page abstract, and there were several stories of a paper and slides having arrived at the rapporteur's hotel at noon, in time for the afternoon presentation.

Unfortunately, the sponsoring societies had underestimated attendance and did not have sufficient abstract booklets available for those who registered late.

It must also be remembered that the scope of the meeting included all of the aspects of research and production, from the most basic to the most practical. The range of interests and abilities of the attendees covered the same broad scope. Considering these factors, I think it may have been a mistake to use the rapporteur system at all, the system being perhaps better suited to a "specialist" meeting (where "specialist" is narrower of meaning than is "titanium").

A special comment is required on the Russian delegation and their efforts. I have already mentioned their abstracts; with only a couple of exceptions, their papers and comments were also sophomoric. How much of this was due to language problems is difficult to assess, though the ones that spoke were fairly fluent.

As usual, I have derived some interesting statistics from the list of attendees and the program.

	US	UK	France	Germany	Japan	Russia	Other
Attendees	111	198	28	24	9	22	24
Contributed Papers	52	29	3	3	9	12	3

It may be seen that the US contributed about 50% of the papers, but represented only about 25% of the attendance. From some of the remarks I heard it was obvious that many more US scientists would have come, but for the recent severe restrictions on overseas travel; many of those who did manage to attend had had great difficulty in rounding up funds. It was also interesting that of the 198 UK attendees, 69 were from Imperial Metal Industries, the principal UK producer of titanium.

It was possible to break down the attendance list to indicate the source of the attendees by function and the source of the papers by organization. Of the attendees, 54% are engaged in R&D and teaching, 15% in production, 11% in sales, 4.5% in government, 3.5% in administration and there were 12% whom I could not classify because they did not indicate a position title. On the other hand, 44% of the papers presented originated in industry, 21% were from universities, 15% from government sources, 11% from Russia, and 9% from research institutes. It is clear that the titanium industry is heavily engaged in research and development.

In the main portion of this report I will try to discuss briefly those papers which I consider made a significant contribution to the

Conference. Appendix A will give the complete program of the Conference including the titles and authors of all the papers presented. Proceedings will be published in about a year.

The Processing of Titanium

E. Detemple, A. Gerhardt and W. Knorr described the chemical homogeneity changes accompanying an ingot-size scale-up from 1000-kg ingots, 450 mm in diameter to 10,000-kg ingots, 950 mm in diameter. Commercially pure and Ti-6Al-4V ingots were produced by double melting. The properties of wrought products of both titanium materials showed no influence of ingot size or position within the ingot, although there were minor chemistry variations due to segregation. The authors of this paper were subjected to some severe questioning from the audience, but did not retreat from their contentions.

S. Z. Bokshtenin and S. T. Kishkin used X-ray and autoradiographic techniques to study microsegregation in Ti alloys. They found that during the β-α transition β- stabilizers move along the interfaces of α platelets, while α- stabilizers diffuse to the center of the α grain. The authors claim that the diffusion mobility during the phase change is at least 3 orders of magnitude higher than for bulk diffusion.

C. E. Armantrout and J. T. Dunham reported on a study of electroslag melting of Ti sponge. They reported sound ingot structures of acceptable chemistry. There is one problem: the hydrogen content of the sponge is not reduced by electroslag melting, eliminating high hydrogen (water leached) sponge from consideration for this method of melting.

Prof. S. G. Glazunov described the development history and current status of Ti in the USSR. His paper had but one redeeming feature; the revelation that the Soviets require macro and microstructures of Ti to correspond to standard samples and that they use a 9-step scale for microstructures and a 14-step scale for macrostructures.

Beta processing was the subject of two interesting reports, one by T. E. Green and C.D.T. Minton of IMI and the other by J. E. Coyne of Wyman-Gordon. The studies were similar and complementary. It was clear that β forging is applicable to the whole range of Ti alloys, provided suitable precautions are taken in later processing stages. Thus, forgeability is markedly improved (the temperature is higher) without loss in final properties; β forging leads to greater ease of production of complicated components and also to better creep resistance and fracture toughness in certain cases (strongly β- stabilized alloys).

Chemical and Environmental Behavior

J. B. Cotton and J. G. Hines showed that surface contamination of Ti by Fe, Cu or Pt during processing will markedly increase the rate of hydrogen pickup in service in chemical environments. They also showed that anodizing the exposed surfaces prevents this from occurring, thus preventing brittle failure. The techniques of anodizing are described in the second part of the paper.

A. Takamura, K. Arakawa and Y. Moriguтchi investigated the efficacy of single metal additions to Ti to improve its corrosion resistance in hot concentrated HNO_3. They found that an addition of 5% Ta was the most effective, that more Ta was not beneficial and that the presence of a few milligrams of Ti ion in solution was the most dramatic method to reduce Ti corrosion.

T. J. Murphy presented a technique for measuring the anodic breakdown residual potential of a standard area of any titanium surface. This voltage is determined rapidly and can be used as an index of expected corrosion behavior. The critical voltage which defines the conditions for the onset of pitting is a function of alloying content, heat treatment and surface preparation.

M. J. Mindel and S. R. Pollack studied the oxidation of thin films of vapor-deposited Ti. They found that an oxide film nucleates homogeneously on the surface of a smooth substrate and that the oxide islands are about 10 monolayers thick when they coalesce to cover the entire surface. The data indicate that the oxide contains excess metal atoms relative to the stoichiometric composition and that it is formed by cation diffusion.

C. E. Shamblen and T. K. Redden studied the air contamination and embrittlement of several titanium alloys during elevated temperature exposure. They determined the time-temperature dependency to form a brittle layer on Ti-6Al-2Sn-4Zr-2Mo and compared this to published data for other Ti alloys. Microhardness measurements provided the significant input data; the Dewey Van Ostrand and Arrhenius equations allowed the determination of the air contamination rate. They were also able to show that the loss of tensile ductility due to air contamination was proportional to the thickness of the oxygen enriched surface layer. The rate of ductility degradation was shown to be smaller for the 6242 alloy than for Ti-8Al-1Mo-1V and Ti-679 alloy (Ti-2.25 Al-11Sn-5Zr-1Mo-.25Si), respectively.

Two mechanisms for stress corrosion cracking (SCC) of Ti alloys were presented. T. R. Beck presented a completely new hypothesis based on a single important experimental fact. He had found that SCC of Ti-8Al-1Mo-1V occurred only in the presence of three ions in aqueous solutions-chloride, bromide and iodide. Therefore, his hypothesis is based on the assumption that halide adsorption at the tip of an advancing crack is the rate controlling

step. A complete model based on this assumption is presented; this model also accounts for experimental SCC data on cathodic potential, current and propagation velocity. In addition to pointing out the possibility of a rate controlling step other than hydrogen adsorption, the new theoretical formulation casts some doubt on the validity of the mechanisms involving hydrogen embrittlement or oxide wedging.

On the other hand, D. T. Powell and J. C. Scully presented considerable evidence which they interpreted as providing substantiation for the role of hydrogen in the SCC of Ti. They studied SCC of Ti-5Al-2.5 Sn in aqueous environments containing NaCl and of pure Ti as well as the alloy in methyl alcohol containing 1.5% HCl and 1.06% H_2O. The authors believe that hydride formation is the key to SCC in Ti alloys; they do not find hydrides in non-susceptible alloys. In their mechanism the critical step is the creation of bare (oxide free) metal at the surface of the crack tip, thus allowing the adsorption and ingress of hydrogen.

D. N. Fager and W. F. Spurr studied the tendency for SCC as a function of alloying elements which changes the percentages of the α and β phases. They found that two phase alloys containing Mo and V exhibit stress corrosion cracks in the α phase, but not in the β or martensite phases. In these alloys susceptibility to stress corrosion decreases as the amount of second phase (β or martensite) increases due to variations in composition or heat treatment. In addition, these authors have observed co-planar dislocations in the non-susceptible Ti-8Al-1 Mo-1V martensite, indicating that a composition influenced surface feature (via an adsorption or electrochemical mechanism) rather than a structural feature is the factor controlling susceptibility of individual phases.

U. Zwicker and E. Kalsch showed that annealed Ti alloys containing Al and V are much more susceptible to crack propagation in air at 450-600°C than if the alloys are cold worked about 35%. The plastic deformation does not inhibit crack formation beneath the oxide layer, but it does stifle crack propagation.

S. P. Rideout, R. S. Ondrejcin and M. R. Louthan presented a summary of a long series of papers on hot salt corrosion. They report an apparent threshold temperature of $\sim$425°F, below which no hot salt cracking occurs. They also report that susceptibility to hot salt SCC is a strong function of the Al content of the alloy, but they are unable to isolate a single mechanism for this effect; three are suggested. They propose that hydrogen embrittlement is associated with both crack initiation and propagation, but do not offer conclusive evidence to support their hypothesis.

Prof. R. Staehle, the rapporteur, presented a trend summary which I believe related all that we really know about SCC in Ti alloys. His six points were:

1. Increasing Al content accentuates cracking regardless of environment. The presence of Al either favors coplanar slip (which results in a high stress concentration) or hydride formation (which means that considerable hydrogen is in solution and available to promote embrittlement).

2. Second phases inhibit cracking.

3. Cracking can be minimized by manipulating the orientation of the cleavage plane.

4. The intergranular mechanism of failure observed in lean alloys may mean that a simple dissolution is operative.

5. There is a tendency toward transgranular (cleavage) SCC failures in highly alloyed Ti.

6. The presence of prior fatigue cracks is deadly in a stress-corrosion situation.

Physics, Thermodynamics and Kinetics

E. W. Collings and J. G. Ho reported on a study of magnetic susceptibility and low temperature specific heat of Ti-Al alloys to 30 $^{a}/_{o}$ Al and the full range of Ti-Mo alloys. The combined results for Ti-Al alloys indicate that the density of electronic states, n(E), is a slowly varying quantity to 15 $^{a}/_{o}$ Al with a deep minimum at the composition Ti_3Al. The indication is that this anomaly is accompanied by another in the lattice parameter. For the Ti-Mo alloys the combined results of magnetic susceptibility and low temperature specific heat show that n(E) increases rapidly with increasing Mo concentration and the structure changes to bcc. It is not clear whether the structural change is due to the change in n(E) or the change in the Debye characteristic temperature. The authors conclude that the influence of Al produces little change in the Fermi surface, whereas Mo, being a transition metal with extensive solubility in Ti, forms a series of binary alloys in which the crystal structure and other properties can be understood in terms of the electron-atom ratio. Since Ti is itself an early transition metal, alloying it with another such metal leads to the eventual stability of the bcc structure at a fairly high electron-atom ratio (4.3-6.5 in the e/a range).

M. Hoch, J. V. Hackworth, R. J. Usell, and H. L. Gegel reported the first results gathered with a newly developed technique fo activity determination in alloys. The technique utilizes a triple

Knudsen cell and a pure enriched natural isotope as the standard reference state. The alloy to be studied is placed in a Knudsen cell adjacent to a second cell containing the standard reference isotope. The effusing molecular beams are mixed in the third cell (mounted above the first two) and the mixed beam becomes the ion source of a time-of-flight spectrometer. Since the ion beam intensities are proportional to their vapor pressures in the Knudsen chambers, the ratio of intensities gives a direct determination of the activity of the component in the alloy. The activities of both components in bcc Ti-Cu and Ti-Al alloys were measured over certain composition and temperature ranges. The results indicate that for an α stabilizer the interaction coefficient is negative and the internal energy and entropy of the alloy are lowered relative to the situation with β stabilizing elements, where the interaction coefficient is positive. These considerations led the authors to postulate that a Ti-Ga alloy would have a strongly negative interaction coefficient, resulting in an alloy with a high β transus. Such an alloy is now being examined.

J. D. Boyd provided the first direct evidence that hydride precipitation may be deformation assisted. He studied annealed Ti-8Al-1Mo-1V which was hydrogen charged at 650°C in a Sievert's apparatus. At a hydrogen concentration of 800 ppm, considerable spontaneous hydride precipitation occurred. With hydrogen concentrations in the range 200-600 ppm thin hydrides were observed to form on the slip planes in specimens deformed to about 2%. The strain-induced hydrides show no tendency to become thicker than the slip band. Dark field microscopy was used to prove that the hydrides actually lie in the slip planes. The data indicate a significant barrier to hydride nucleation. It is indicated as well that hydride precipitation is associated with the slow strain rate embrittlement of Ti and the stress corrosion cracking of Ti in aqueous environments.

Deformation

S. Weissmann and A. Shrier reported an elegant X-ray divergent beam study of oxidized Ti crystals. Their analysis is based on the measurements of more than six independent sets of lattice planes sampled in different crystallographic directions. They conclude that the unusually high hardening accompanying the oxidation of Ti is due to the fact that the solid solution has a high degree of long range ordering with the oxygen atoms occupying the octahedral sites in alternating layers.

W. R. Tyson described a new method of calculating the strengthening effect of interstitial elements in Ti and Zr. He proposes a mechanism in which the strengthening is due to the mechanical obstruction of the movement of the atoms at the core of a moving dislocation. This calculation gives (higher) values very much closer to experimental information than does the

simpler model of an elastic interaction between the strain field of the dislocation with that of the solute. There were in the audience some advocates for a Peierls mechanism controlling flow: Tyson responded that the mechanism must be linked to the presence of interstitial solutes because the strength rises very rapidly with increasing solute concentration.

H. Conrad, R. Jones and J. Hull presented a summary of their work on deformation dynamics and work hardening of Ti as a function of interstitial content, grain size and temperature. Their analysis, based on the concepts of thermally activated flow, supports the view that the rate controlling step in deformation of Ti at low temperatures is the motion of dislocations on first order prism planes, over barriers associated with individual interstitial atoms. The activation energy for this process is 1.25 eV ($0.2\mu b^3$).

C. J. Beevers reported on the influence of hydrogen on the fatigue behavior of Ti. He found that the presence of up to 140 ppm of hydrogen raised the S-N curve and the fatigue limit of Ti. Metallographically, he found that the presence of twins was intimately associated with the development of permanent fatigue damage. Further, fatigue damage was only associated with parallel sided $\{11\bar{2}1\}$ twins and not with lenticular $\{10\bar{1}2\}$ twins. He believes that hydrogen increases the fatigue failure stress because the presence of hydride precipitates restricts twin formation.

Phase Transformations and Heat Treatment

C. Hammond and P. M. Kelly have detected three types of martensite which can exist simultaneously in at least one β-stabilized alloy, Ti-5Mn. A small number of martensite plates have no internal substructure, are hexagonal in nature and have approximately the Burger's orientation to the matrix. The second type of hexagonal martensite consists of a stack of $\{10\bar{1}1\}_{\alpha}$ twins. The third type of martensite is fcc and is twinned on one or two sets of $\{111\}$ planes. In the paper the complete orientation relationships between the martrix and the three martensites are given as well as the strains accompanying the transformation.

By far the most complete paper on martensite, ordering and omega phase formation is one summarizing a long series of experiments and written by M. J. Blackburn. The several different martensites, the systems in which the omega phase appears and a discussion of ordering in binary Ti-Al and ternary Ti-Al-Zr and Ti-Al-Ag alloys is presented. Blackburn considers that the ordered phase in the Ti-Al system is approximately Ti_3Al and exists in the DO_{19} type structure.

However, P. C. Gehlen reported a very careful X-ray examination of a single crystal of Ti_3Al. The sample was ordered for 840 hours at 875°C by which treatment the superstructure lines were rendered sharp and easily detectable. This ordered structure persisted to

1050°C, the maximum temperature limit of the X-ray camera. Gehlen has also been able to perform the best crystal structure determination made to date on Ti_3Al. He finds that the structure is hexagonal but not DO_{19} (Ti_3Sn type). Several of the superstructure peaks are 5-10 times as intense as would be predicted on the basis of the DO_{19} structure. The complete structure determination is now being made.

Two papers were devoted to the study of the Ti-Cu system. The paper by J. C. Williams, D. H. Polonis and R. Taggart covers a range of compositions, and includes an investigation of the nature of the martensite and its substructure, the decomposition of the β phase by nucleation and growth and the isothermal decomposition of the martensite. The second paper by R. E. Goosey and P. A. Blenkinsop is more of a classical study of the precipitation hardening sequence in a single composition, Ti-2.5 Cu. The precipitation reaction is followed by electron microscopy, the optimum heat treatments are given and the resulting strengths discussed.

H. Margolin, P. A. Farrar and M. Greenfield presented a study of the influence of thermo-mechanical processing on a Ti-5.25 Al-5.5V-0.9Fe-0.5Cu alloy. By a combination of high temperature forging (within 75°F of the 1700°F beta transus), solution treatment at the same temperature, followed by aging at 1150°F, a fracture strength of 339,000 psi was obtainable at a fairly fine grain size. This material had a microstructure of equiaxed α in a β matrix.

P. J. Fopiano and C. F. Hickey, Jr. presented the results of a heat treatment study on Ti-6Al-4V, Ti-6Al-6V-2Sn and Ti-8Al-1V-1Mo. As expected, the greatest hardness was achieved by solution treatment just below the β transus. They also found a unique minimum strength for all three alloys upon solution treatments at about 1500°F. This minimum defines the lower limiting temperature of true β stability.

Their aging curves also show that significant aging will not occur unless the solution treatment is carried out at a temperature near the β transus.

Alloying of Titanium

H. W. Rosenberg essentially describes the route by which the alloy Ti-6Al-2Sn-4Zr-2Mo was developed. An evaluation of the embrittling effects of Al, Sn, Zr and O showed them to be additive. An equation is presented which shows that Sn has 1/3 the embrittling effect of Al, Zr is 1/6 as effective as Al and oxygen is 10 times as effective. Using this equation to design an alloy which will present an as-exposed post creep ductility of 10% elongation and 20% reduction in area, one finds that for 1000°F exposure a composition of Ti-6Al-2Sn-2Zr is most stable. This alloy has low strength, however, and Mo was added

to increase the strength by creating a lean β alloy. Since a mild Zr-Mo strengthening was observed, the Zr concentration was increased resulting in the final commercial specification.

A. Ayvazian and R. Colton showed that the old saw on the adverse effect of C and O on ductility of Ti alloys does not necessarily hold for the high strength α-β alloys. The alloys, based on the Ti-6Al-6V-2Sn composition, were slightly modified mainly by additions of mild β stabilizers and additional C and O. The optimum alloy contained 0.12% C and 0.11% O and for an aging temperature of 1150°F yielded at 220,000 psi with final elongation of 12% and acceptable low temperature impact strength.

K. S. Jepson, L. Larke and C. A. Stubbington investigated the influence of Al, In and Ga on creep and stress-rupture of Ti. They found that alloys containing Ga were stronger than those containing Al for a smaller alloying addition and were less prone to the formation of an ordered phase and the stress-corrosion and embrittlement problems which accompany the presence of this (Ti_3X) phase. This result bears out the prediction of Hoch, Hackworth, Usell and Gegel reported earlier as a result of their thermodynamic investigation.

Several authors explored the possibility of modifying a stable α-Ti alloy in order to produce a wide range of properties. Each group ended up with slightly different compositions showing improved properties, but no one has produced an alloy capable of significant service at much above 1000°F (535°C). It was pointed out that there are still untried compositions, that dispersed phase strengthening can be exploited and that the potential of Ti composites has hardly been touched. Yet we were left with the nagging thought that very soon in this age of rising temperatures, the chemical reactivity of the titanium itself will become the limiting factor.

D. B. Hunter and S. V. Arnold described their quest for a high hardenability, aging, weldable alloy with usable ductility. They derived a composition Ti-8Mo-8V-2Fe-3Al, a metastable β alloy. As aged the alloy yielded at 180,000 psi and exhibited 7% elongation at room temperature. But even having searched for a weldable alloy is no guarantee of success. Weldability tests showed sound beads to be readily obtainable which exhibited yield strengths of 120,000 psi and 4% elongation. But, post-weld aging raised the weld metal yield strength to 180,000 psi with only 2% elongation.

C. J. Kropp and A. Hurlich described the development of a new alloy for cryogenic use. It was necessary to do this because the development of the "extra low impurity" grades of Ti-6Al-4V and Ti-5Al-2.5Sn for cryogenic application had caused a reduction in yield stress of as much as 20% compared to the commercial grades of these same alloys. The final alloy composition which they

have selected is Ti-5Al-2.5Sn-2.5V-1.3Nb-1.3Ta. This material, even with the extra low impurity specification, has a room temperature yield stress of 120,000 psi, is comparatively notch insensitive, weldable and shows 10% greater fracture toughness at $-423^{\circ}F$ than at room temperature. C'est magnifique!

Applications

Electron beam welding of Ti is acknowledged as the best welding technique for this material. However, this process is very time consuming (and therefore expensive) because of the necessity to evacuate the welding chamber each time the work pieces are changed. M. G. Bennett reported on a study in which he had electron beam welded Ti-6Al-4V in a partial vacuum (10 microns) instead of a full vacuum (0.1 micron). The tensile properties of these welds are not less than those shown by specimens welded in a full vacuum and are only marginally different from the unwelded alloy. Metallographic examination has revealed the absence of contamination. In addition he has shown that a high-voltage high-speed welding condition produces welds completely free of porosity.

R. A. Rosenberg, G. S. Irons and K. J. Pulkonik report on a study of submerged arc welding of Ti and the search for an appropriate flux. They point out that welding thick sections by inert gas welding is an expensive and time consuming process because of the minor amounts of metal that are deposited in each welding pass. The relatively crude thermodynamic considerations required to find a stable non-reactive flux are indicated. They have found a composition based on $CaCl_2$ which will not react with Ti at welding temperatures and which protects it from contamination during welding. In the discussion it was pointed out that this search in the USSR led to a flux whose main constituent is CaF_2. It would appear that submerged arc welding is now a feasible process, but that some considerable development remains to be done regarding welding procedures and the establishment of satisfactory standards.

The question of the mechanism of the pore formation along the fusion boundaries in welded Ti has proven to be particularly difficult. H. R. Clarkson, A. E. Burn and E. A. Taylor presented their most recent information which at least identifies the responsible gas. They performed mass spectrometry on welds made in argon on pure Ti and Ti-6Al-4V to identify hydrogen as the responsible gas. Next, they did a melting study as a function of the dew point of the argon atmosphere to show that considerable hydrogen can be retained if a relatively wet gas is used for melting or welding protection. In this regard Ti-5Al-2.5 Sn was shown to be very much more sensitive to the presence of water in that at a dew point of $-50^{\circ}F$ it absorbed and retained 2.5 times as much hydrogen as did pure Ti.

M. Tiktinsky reported on a study of the properties of large heat treated forgings of Ti-6Al-4V. He found the static and fatigue properties to be as expected and the fracture toughness was the same as for SAE 4340 steel; thus on a K_{IC}/Wt basis the Ti alloy is better. He is now studying the behavior of smaller forgings electron-beam-welded together to produce a larger body. He has found that the static properties of the welded forgings are the same as those of the one-piece forgings, but that the electron beam welded samples show fatigue properties reduced by 33% at 10^7 cycles. He has also examined the properties of β-forged specimens and finds that their fracture toughness is raised by 33% and electron-beam welded β-forged components show no loss of fatigue strength.

J. E. Bowers, N. J. Finch and M. G. Burberry have studied the wear and fatigue properties of Hylite 50 (Ti-4Mo-4Al-2Sn) coated with sprayed Mo, oxidized, or hard chromium plated. The Mo sprayed coatings spalled in the wear tests, and some of the oxidized specimens were distorted while others exhibited low fatigue properties. They were able to obtain acceptable results with chromium plating, but only after having used a complex series of treatments: pickle in hot concentrated HCl, Ag plate to 2.5μm, heat treat in vacuum at 500°C for ½ hour to reduce hydrogen content, clean, plate with 25 μm of Ni, heat treat ½ hour at 6-700°C to improve adhesion, and finally Cr plate. After this treatment the plate did not spall under the conditions of the most severe wear test. It seems to me that this is an expensive and arduous procedure compared to that of Professor Piontelli's (ONRL-19-68). I suspect that since Piontelli's Cr plated Ti specimens will withstand a tight 180° bend followed by a reverse 180° bend, the adhesion of that Cr is probably sufficiently good to pass the wear test mentioned above.

L. P. Jahnke described the use of Ti in jet engines. Ti is now used for 15-35% of the total weight of jet engines being designed today--with the least Ti being used in the highest Mach number engines, since Ti is "structurally noncompetitive with other materials over about 900°F." Thus, he pointed out that Ti is mainly used in the front or cooler end of the engine. He lamented the fact that 70-90% of a Ti forging ends up as machining chips; pointed out that newly developed alloys having greater potential are being produced, but that much work remained; and indicated that electron beam welding (very expensive and time consuming) was used everywhere possible. He produced a long list of Ti problems beginning with ingot segregation and the inability to produce large precision forgings, listed such problems as erosion, unexplained poor fatigue behavior of large forgings, fretting and auto-ignition, and ended up by re-emphasizing the ever present dangers of hot salt corrosion above 650°F and oxidation embrittlement which results from long exposure over 900°F. I must caution the reader not to get the impression that Lou Jahnke is anti-titanium, but by his own admission, he is a titanium user, not a salesman!

A. H. Meleka described the use of Ti alloys in the Concorde jet engine. He pointed out that this usage was all very conventional. But he did drop a bombshell! He indicated that new developments in the super alloys threaten to supplant Ti at temperatures over 700°F instead of just over 900°F. Since reinforced plastics are rapidly increasing their span toward 500°F, it was predicted that the jet engine designer of the 1970's may prescribe Ti only for the narrow range of 5-700°F, unless the Ti alloy development people warm up to their work.

The airframe manufacturers had their say next. R. V. Carter described the usage of Ti in the Boeing SST. Ti alloys account for more than 60% of the weight of the airframe. However, assembly of most of the structure will be by mechanical fastening, not welding, in spite of the weight penalty this entails, primarily because welded Ti structures must be stress-relieved and/or reheattreated. A. J. Chivers of the British Aircraft Corporation did a complete exercise to show the potential savings inherent in the use of Ti for airframe construction. But, to arrive at this conclusion, he first had to assume "that very extensive welding fabrication would be possible--and further, that manufacturing techniques would be sufficiently well developed to construct large thin-gauge sheet structures within acceptable welding distortion limits and with consistent weld quality." Saying the same thing another way, Chivers said that for his calculations he had presupposed "a titanium fabrication technology which will require an extensive period of manufacturing and structural development effort lasting 4-6 years for achievement."

Summary

What did this Conference show? I believe that it showed at once, that the full potential of titanium has yet to be attained and that although definite progress has been made on many fronts, titanium still has a handful of lingering problems. Progress has definitely been made in forging techniques, yet precision forging practice is wanting. The influence of contamination in processing on later behavior has been elicited, and anodizing techniques have been devised to protect against contamination. Oxidation and corrosion are still topics of interest, but now the precise oxygen contamination rate has been determined and it has been shown that the loss of tensile ductility is exactly proportional to the depth of oxidation.

Stress-corrosion cracking and the accompanying catastrophic failure continue to be the most serious of titanium's problems. Unfortunately, all we really have in this area, even today, are the six generalizations given by R. Staehle and a few individual "fixes" for particular problems. In this day and age, the surprise such things as the titanium oxidizer-bottle failure causes us is not simply awkward, not simply an embarrassment, but such incidents show the real degree of our impotence--our lack of understanding.

At this Conference we saw the introduction of yet another reasonable theory for SCC--now we have five. One can only hope that the current massive effort being concentrated on this problem will soon bear fruit. I will not soon forget the little Welshman that got in the last words at the corrosion session--"It looks as if the corrosion bods do not want to solve the SCC problem--it'd put them out of work." We know that is not really the case--but we must admit that it begins to look like that.

Such "esoteric" things as magnetic susceptibility, low temperature specific heat, activities in solid solution, regular solution theory and the single crystal elastic moduli are now being used to provide a firm understanding of the behavior of Ti and to point the way to new alloys with specific properties. The role of the interstitial elements is now better understood. At last we have firm experimental evidence that hydride nucleation can be deformation assisted; that the high hardness of oxidized α-Ti is really due to the asymmetrical strains resulting from the ordering of the oxygen atoms; and that the influence of the hydride in both static and dynamic stressing is to restrict the normal modes of deformation. On the other hand, it begins to look as if we still do not have the immensely complicated Ti-Al system sorted out, although the martensite, omega and ordering reactions and their crystallography do seem to be much better understood.

Alloy development seems to be proceeding at a reasonable rate; new alloys for elevated temperature and cryogenic service were described. However, it is clear from the final remarks of the jet engine manufacturers that this process must be improved rapidly, lest the market be eroded from the top by the superalloys and from the bottom by fiber-reinforced plastics.

Second only to the problem of stress-corrosion cracking is the immense problem of welding titanium. Electron beam welding seems to be satisfactory in many cases, but aside from the time and expense, even this is not the final answer because the fatigue properties of welded structures are not as good as they should be. Also, welding leaves large residual stresses which cause distortion, making post welding heat treatment a necessity. The need for further rapid development of welding technology was made plain by the airframe manufacturers. Such advances are necessary to allow Ti to reach its full potential as a structural material.

Appendix I - Program

SESSION I. Introduction

Chairman: I. Jenkins, President, The Institute of Metals
Co-Chairman: Mr. N. E. Promisel, Past Trustee American Society for Metals.
Secretary: R. E. Moore, Secretary, The Institute of Metals

Opening Address by the President of The Institute of Metals

Introductory Lectures
- (i) Titanium in U.S.A. - T. W. Lippert (Titanium Metals Corporation of America, New York)
- (ii) Titanium in Europe - P. Hodgkinson (Imperial Metal Industries (Kynoch) Ltd., Birmingham 6, England)

SESSION II. Processing of Titanium

Chairman: W. R. Hibbard
Secretary: C.D.T. Minton

Section A - Primary Fabrication
Rapporteur: A. D. Busby

1. Solidification Structure of Titanium Alloys, Stan A. David and Harold D. Brody (University of Pittsburgh, Pennsylvania)

2. Research on the Quality of Commercially Pure Titanium and Ti-6Al-4V Ingots, E. Detemple, A. Gerhardt and W. Knorr (Fried, Krupp, Essen, Germany)

3. Chemical and Structural Microheterogeneity, Diffusion and Mechanical Properties of Titanium Alloys in Connection with Peculiarities of Phase Transformation, S. Z. Bokshtenin, T. A. and S. T. Kishkin (USSR)

4. Selection of Vacuum Arc Melting Parameters to Provide Ingot Chemical Homogeneity, V. I. Dobatkin and N. F. Anoshkin (USSR)

5. Shrinkage Phenomena of Titanium Ingots During Solidification and Cooling, V. V. Tetukhin (USSR)

6. Properties of Wrought Shapes Formed From Electroslag-Melted Titanium, C. E. Armantrout and J. T. Dunham (US Bureau of Mines, Washington, D.C.)

7. Titanium in the USSR, S. G. Glazunov (USSR)

Section B - Secondary Fabrication
Rapporteur: H. D. Kessler

1. The Effect of Beta Processing on the Properties of Titanium Alloys, T. E. Green and C.D.T. Minton (Imperial Metal Industries, Ltd., (I.M.I.), Birmingham, Eng.)

2. The Beta Forging of Titanium Alloys, J. E. Coyne (Wyman-Gordon Co., Worcester, Mass.)

3. Heavy Press Forging of Large Titanium Parts for Aircraft and Aerospace Applications, Thomas G. Byrer and Francis W. Boulger (Battelle-Columbus Laboratories, Ohio)

4. Forgings in Titanium Alloys, J. V. Scanlan and G.J.G. Chambers (High Duty Alloys, Ltd., Redditch, Worcs., Eng.)

5. The Mono Graf Casting Process, R. E. Warnock and P. L. Worthington (Howmet Corporation, Niles, Ohio)

6. Titanium Casting, S. G. Glazunov (USSR)

<u>SESSION III. Chemical and Environmental Behavior</u>

Chairman: H. Bomberger
Secretary: U. Zwicker

Section A - General Corrosion and Oxidation
Rapporteur: J. B. Cotton

1. Reaction Rate of Titanium and Titanium Alloys With Titanium Lower Chlorides, E. K. Kleespies and T. A. Henrie (US Bureau of Mines, Reno, Nevada)

2. Hydriding of Titanium in Chemical Plant & Protective Measures, J. B. Cotton, J. G. Hines, F. Manton and M.E.D. Turner (I.M.I., Ltd., Birmingham 6, Eng.)

3. Corrosion Resistance of Titanium and Titanium-5% Tantalum Alloy in Hot Concentrated Nitric Acid, Akira Takamura, Kaname Arakawa and Yasuo Morigutchi (Kobe Steel, Ltd., Kobe, Japan)

4. Utilization of Anodic Breakdown of Titanium Alloys as a Method of Characterization, T. J. Murphy (Titanium Metals Corporation of America, Nevada)

5. The Oxidation of Titanium Films, M. J. Mindel and S. R. Pollack (Univ. of Pennsylvania, Philadelphia, Pa.)

6. Air Contamination and Embrittlement of Titanium Alloys, C. E. Shamblen and T. K. Redden (General Electric Company, Evendale, Ohio)

7. Titanium Electrode for the Manufacture of Electrolytic Manganese Dioxide, Dr. Keiichi Shimizu (The Furukawa Electric Co., Ltd., Tokyo)

8. Corrosion Test for Evaluating the Corrosion Resistance of Titanium, S. Morioka, R. Otsuka and K. Nakano (Japan)

9. Studies of Phase Diagrams in Connection with Corrosion Properties of Titanium and its Alloys, L. I. Prjachina (USSR)

Section B - Stress Corrosion
Rapporteur: R. Staehle

1. Electrochemical Mechanism in the Stress Corrosion Cracking of Titanium Alloys, T. R. Beck (Boeing Scientific Research Laboratories, Seattle, Washington)

2. Stress Corrosion Cracking of α Titanium Alloys at Room Temperature, D. T. Powell and J. C. Scully (Univ. of Leeds, England)

3. Some Characteristics of Aqueous Stress Corrosion in Titanium Alloys, D. N. Fager and W. F. Spurr (The Boeing Company, USA)

4. Ambient Temperature Stress Corrosion Cracking in Ti-8Al-1Mo-1V, Irving S. Shaffer and Alan Lawley (Naval Air Development Center, Johnsville, Warminster, Pa.)

5. Stress Corrosion Cracking in Titanium and Titanium Alloys, W. K. Boyd and J. D. Jackson (Battelle Memorial Institute, Columbus, Ohio)

6. Cracking of Titanium-Alloys Under Stress During Oxidation in Air (U. Zwicker and E. Kalsch, Universität Erlangen-Nurnberg, Germany)

7. Stress-Corrosion Cracking of Titanium and Ti-Al Alloys in Methanol-Iodine Solutions, A. J. Sedriks, J.A.S. Green and F. W. Slattery (Martin Marietta Corporation, Baltimore, Maryland)

8. Effects of Halogen Containing Hydrocarbons Upon Stressed Ti-6Al-4V Alloy, K. Kamber, E. G. Kendall and L. Raymond (Aerospace Corp., Los Angeles, Calif.)

9. Hot-Salt Stress Corrosion Cracking of Titanium Alloys, S. P. Rideout, R. S. Ondrejcin and M. R. Louthan, Jr. (E. I. du Pont de Nemours & Co., Aiken, South Carolina)

SESSION IV. Physics, Thermodynamics and Kinetics

Chairman: R. Eborall
Secretary: H. L. Gegel
Rapporteur: A. D. McQuillan

1. Physical Properties of Titanium Alloys, E. W. Collings and J. C. Ho (Battelle Memorial Institute, Columbus, Ohio)

2. Thermodynamic Properties of the Body-Centered Cubic β Phase in the Titanium-Copper and the Titanium-Aluminum Systems, M. Hoch, J. V. Hackworth, and R. J. Usell (Univ. of Cincinnati, Ohio)

3. Calculation of Regular Solution Phase Diagrams for Titanium Base Binary Systems, Larry Kaufman and Harold Bernstein (ManLabs, Inc., Cambridge, Mass.)

4. The Single Crystal Elastic Moduli of βTi and Ti-Cr Alloys, E. S. Fisher and D. Dever (Argonne National Laboratory, Argonne, Illinois)

5. Computer Experiments on Point Defect Configurations and Energies in Ti-M Systems, J. R. Beeler, Jr. (North Carolina State Univ., Raleigh, North Carolina)

6. Behavior of Hydrogen in Titanium and Its Alloys by Internal Friction Measurement, Mayumi Someno and Hiroshi Saito (Tokyo Institute of Technology, Tokyo, Japan)

7. Deformation-Assisted Nucleation of Titanium Hydride in an Alpha-Beta Titanium Alloy, J. D. Boyd (Battelle Memorial Institute, Columbus, Ohio)

8. Stress Induced Diffusion of Carbon and Oxygen in Titanium, D. R. Miller and K. M. Browne (CSIRO, Univ. of Melbourne, Australia)

9. Studies of Interaction of Titanium with Other Elements, I. I. Kornilov (USSR)

SESSION V. Deformation

Chairman: A. H. Cottrell
Secretary: H. Otte

Section A
Rapporteur: R. J. Wasilewski

1. Strain Distribution in Oxidized Alpha Titanium Crystals, S. Weissmann and A. Shrier (Rutgers, New Brunswick, N.J.)

2. Interstitial Strengthening of Titanium Alloys, W. R. Tyson (Trent Univ., Peterborough, Canada)

2(a) Phase Transformations During Welding and Mechanism of Delayed Cracking of Titanium Alloys, Dr. M. Kh. Shorshorov (USSR)

3. Effect of Interstitial Content and Grain Size on the Mechanical Behavior of Alpha Titanium below $0.4T_m$, H. Conrad, R. Jones and J. Hall (The Franklin Institute Research Laboratories, Philadelphia, Pa.)

4. Hydrogen Embrittlement of Titanium and its Alloys, V. A. Livanov and B. A. Kolachev (USSR)

4(a) Hydrogen Embrittlement of Titanium as Part of the Problem of Cold-Brittleness of Metals, M. B. Bodunova, I. V. Goinin and B. B. Chechulin (USSR)

5. Effect of Cyclic Stresses on Unalloyed Polycrystalline Titanium, P. G. Partridge and C. J. Peel (Royal Aircraft Establishment, Farnborough, Hants, Eng.)

6. Fatigue Behavior of α-Titanium and α-Titanium-Hydrogen Alloys, C. J. Beevers (Univ. of Birmingham, England)

7. The Crystallography of Deformation Twinning in Titanium, A. G. Crocker and M. Bevis (Univ. of Surrey, London, Eng.)

8. Slip Modes and Dislocation Substructures in Titanium and Titanium-Aluminum Single Crystals, Thomas R. Cass (Martin Marietta Corp., Orlando, Florida)

Section B
Rapporteur: D. Hull

1. Elastic Properties of Dislocations in Titanium, L. J. Teutonico (Fairchild Hiller, Farmingdale, N.Y.)

2. Athermal Plastic Deformation in Commercial Purity Titanium, S. N. Monteiro, A. T. Santhanam and R. E. Reed-Hill (Univ. of Florida, Gainesville, Florida)

3. The Elastic Effects of Twin and Grain Boundaries in Titanium, M. O. Tucker (Univ. of Surrey, London, England)

4. The Hot Plasticity of Ti-6 Al-4 V Alloy, N. J. Grant, W. Ioup, R. Kane (Massachusetts Institute of Technology, Cambridge, Mass.)

5. Transformation Plasticity of Titanium, G. Krause, R. Kot and V. Weiss (Syracuse Univ., New York)

6. Superplasticity in Titanium, F. Jovane (Univ. of Naples, Italy)

SESSION VI. Phase Transformations and Heat Treatment

Chairman: R. I. Jaffee
Secretary: R.T.J. Hubbard

Section A - Phase Transformations
Rapporteur: M. K. McQuillan

1. Thermodynamics of the M_s Points in Titanium Alloys, Yen C. Huang, S. Suzuki, H. Kaneko, and T. Sato (Japan)

2. Martensitic Transformations in Titanium Alloys, C. Hammond and P. M. Kelly (Univ. of Leeds)

3. Continuous-Cooling-Transformation of β Phase in Binary Titanium Alloys, Yen C. Huang, S. Suzuki, H. Kaneko, T. Sato (Japan)

4. The Effect of Cooling Rate on the Transformation of Ti-Nb and Ti-Al Alloys, K. S. Jepson, A.R.G. Brown, J. A. Gray (R.A.E., Farnborough, Hants., Eng.)

5. Some Aspects of Phase Transformation in Titanium Alloys, M. J. Blackburn (Boeing Scientific Research Labs., Seattle, Washington)

6. The Order-Disorder Transformation in Ti_3Al, P. C. Gehlen (Battelle Memorial Institute, Columbus, Ohio)

7. An Electron Microscopy Study of Phase Transformations in Ti-Cu Alloys, J. C. Williams, D. H. Polonis and R. Taggart (Univ. of Washington, Seattle)

8. The Age Hardening of Ti-2½%Cu, R. E. Goosey & P. A. Blenkinsop, (Imperial Metal Industries, Ltd., Birmingham, Eng.)

9. Phase Relationships in Ti-O Alloys, A. Jostsons and P. McDougall (Australia)

10. Phase Transformation of Titanium Alloys by Means of Automatic Transformation Apparatus, Yoru Yukawa, Shitoshi Ohtani, Takashi Nishimura (Kobe Steel, Ltd, Japan), and Takao Sakai (Cincinnati University)

11. Mechanism of the Martensitic Transformation in Titanium and its Alloys, Henry M. Otte (Martin Marietta Corp., Orlando, Florida)

12. The Martensitic Transformation in Titanium Binary Alloys and its Effect on Mechanical Properties, D. W. James and D. M. Moon (Westinghouse Research Laboratories, Pittsburgh, Pennsylvania)

Section B - Heat Treatment and Thermal Stability
Rapporteur: E. F. Erbin

1. The Morphology of the Omega Phase, C. Hammond (Univ. of Leeds, England)

2. The Stability of the Omega Phase in Titanium and Zirconium Alloys, N. A. Vanderpuye and A. P. Miodownik (Univ. of Surrey, England)

3. Theoretical Bases for Creating High-Strength Metastable Beta Alloys of Titanium, N. V. Ageev and L. A. Petrova (USSR)

3(a) The Development of Structure and Mechanical Properties of Titanium Welds, I. V. Gorinin, J. B. Florinsky and B. B. Chechulin (USSR)

4. Strengthening of Titanium Alloys by Shock Deformation, J. F. Breedis and M. K. Koul (Massachusetts Institute of Technology, Cambridge, Mass.)

5. Thermo-Mechanical Strengthening of High Strength Titanium Alloys, H. Margolin, P. A. Farrar and M. Greenfield (New York Univ.)

6. Strengthening Mechanisms During the Heat Treatment of Three Titanium Alloys - Ti-6Al-4V, Ti-6Al-6V-2Sn, and Ti-8Al-1V-1Mo, P. J. Fopiano and C. F. Hickey, Jr. (Army Materials and Mechanics Research Center, Watertown, Mass.)

7. Using of the Jominy Test to Compare the Quench Hardenabilities of the T-A6V and T-A6V6E2 Alloys, J. Moulin, R. Molinier and R. Syre (Pechiney Group Research Center, 38 Voreppe, France)

8. Long Time Stability of Ti-679 After Creep Exposure for Times to 15,000 Hours, V. J. Erdeman, E. W. Ross (General Electric Company, Cincinnati, Ohio)

9. Effect of Elevated Temperature Exposure on the Room Temperature Properties of Titanium Alloys 8Al-1Mo-1V, 6Al-4V, and 4Al-3Mo-1V, Bruce Turbitt and Robert Geisendorfer (The Boeing Company, Seattle, Washington)

SESSION VII. Alloying of Titanium

Chairman: M. K. McQuillan
Secretary: H. R. Ogden

Section A - Alloy Theory and Properties
Rapporteur: H. Rosenberg

1. Titanium Alloying in Theory and Practice, H. W. Rosenberg (Titanium Metals Corp. of America, Nevada)

2. Influence of Carbon and Oxygen on Some Exploratory Ultra-High Strength Alpha-Beta Titanium Alloys, Arthur Ayvazian and Robert Colton (Army Materials and Mechanics Research Center, Watertown, Mass.)

3. The Effect of the Group III Elements, Al, Ga and In on the Creep and Stress Rupture of Titanium at 500°C, K. S. Jepson, L. Larke, C. A. Stubbington (R.A.E., Farnborough, Hants, Eng.)

4. The Effect of Fabrication Variables on the Properties of Age Hardened Ti-2½% Cu, R. E. Goosey (Imperial Metal Industries Ltd., Birmingham, England)

5. Structure and Creep Properties of Ti_7NbAl_3-Base Alloys, F. Prinzbach and H. Winter (Battelle Memorial Institute, Frankfurt, Germany)

6. Properties and Application of Ti-5Al-2Cr-1Fe Alloy (KS150B), Z. Takao, H. Kusamichi, S. Tokuda, K. Miyamoto, Y. Fukuhara (Kobe Steel, Ltd., Japan)

7. The Fatigue Properties of a High Strength Titanium Alloy (IMI680), R. A. Jukes (Lucas Gas Turbine Equipment Co., Ltd., Birmingham, Eng.)

8. The Weldability, Tensile and Fatigue Properties of Some Titanium Alloys, M. H. Scott and W. O. Dinsdale (The Welding Institute, Cambridge)

9. The Influence of Microstructure on the Mechanical Properties of Forged Titanium Alloys, S. J. Ashton and L. H. Chambers (Magnesium Elektron, Ltd., Manchester, Eng.)

10. Elasticity of Titanium Sheet Alloys, A. Zarkades and F. R. Larson (Army Materials and Mechanics Research Center, Watertown, Massachusetts)

11. The Effect of Hydrogen on the Mechanical Properties of Titanium Alloys, I. S. Shaffer and E. S. Tankins (Naval Air Development Center, Johnsville, Warminster, Pa.)

Section B - Alloy Development
Rapporteur: H. C. Child

1. Exploitation of a Simple Alpha Titanium Alloy Base in the Development of Alloys of Diverse Mechanical Properties, W. P. Fentiman, R. E. Goosey, R.T.J. Hubbard and M. D. Smith (Imperial Metal Industries Ltd., Birmingham, Eng.)

2. Creep-Resistant Titanium Alloys, S. R. Seagle and H. B. Bomberger (Reactive Metals, Inc., Niles, Ohio)

3. High Strength Titanium Alloys for Aircraft Gas Turbine Application, J. R. Doyle, D. L. Ruckle and R. A. Sprague (Pratt & Whitney Aircraft Div., E.Hartfort, Conn.)

4. The Role of Depth Hardenability in the Selection of High Strength Alloys for Aircraft Applications, R. M. Duncan and C.D.T. Minton (Imperial Metal Industries Ltd., Birmingham, Eng.)

5. A Study of the Metallurgical Characteristics of Ti-6Al-6V-2Sn Alloy, R. Molinier, J. Moulin and R. Syre (Pechiney Group Research Center, 38 Voreppe, France)

6. Metallurgical Characteristics and Structural Properties of Ti-8Mo-8V-2Fe-3Al Sheet, Plate and Forgings, D. B. Hunter and S. V. Arnold (Titanium Metals Corp. of America, Nevada, and U.S. Army Materials and Mechanics Research Center, Watertown, Mass.)

7. Titanium Alloys for Use in Thermionic Converters, Mechanical and Electrical Properties, Cesium Corrosion Behaviour, Extrusion Tests Under Heating, M. Clemot, J. P. Durand, L. Segurens and E. R. Josso (Centre d'Etudes Nucleaires de Saclay, Gif-sur-Yvette, France)

8. The Development of a Superior Titanium-Base Alloy for Cryogenic Applications, C. J. Kropp, A. Hurlich (General Dynamics Corp., San Diego, Calif.)

SESSION VIII. Applications

Chairman: S. Abkowitz
Secretary: H. Brooks

Section A - Techniques and Processes
Rapporteur: N. F. Harpur

1. High Voltage Electron Beam Welding of Titanium Alloys in Partial Vacuum, M. G. Bennett (Hawker Siddeley Dynamics Ltd., Hatfield, England)

2. Submerged Arc Welding of Titanium: From Theory to Practice, R. A. Rosenberg, G. S. Irons, K. J. Pulkonik (MITRON Research and Development Corp., Waltham, Mass.)

3. Porosity in Argon-Arc Welds in Titanium, H. R. Clarkson, A. H. Burn and E. A. Taylor (I.M.I., Ltd., Birmingham, Eng.)

4. Titanium Hot Forming, T. O. Williams and J. C. Duerden (British Aircraft Corp., Ltd., Preston, Lancs., Eng.)

5. Forming Ti-6Al-4V Sheet Metal in Four Heat Treated Conditions, John C. Chang (Rohr Corp., Chula Vista, Calif.)

6. On the Explosive Bonding and Forming of Titanium, Shigeo Inomata, Asahiko Goto, Kaname Yano, Masayuki Tsuchimoto, Shojiro Shibata, Toshiaki Fujii (Okubo Plant, Kobe Steel, Ltd., Japan) and Mitsuo Kanamoto, Takenao Sakurai (Nippon Oils & Fats Co., Ltd., Japan)

7. Fatigue Characteristics in Titanium Alloy Forgings for Rotary Wing Vehicles, M. Tiktinsky (Lockheed-California Co., Burbank, California)

8. The Production and Properties of Some Wear Resistant Coatings on Titanium-4% Molybdenum-4% Aluminum-2% Tin Alloy (Hylite 50), J. E. Bowers, N. J. Finch, and M. G. Burberry (The British Non-Ferrous Metals Research Assn., London, Eng.)

Section B - Applications Experience
Rapporteur: W. W. Minkler

1. Titanium in Jet Engines, L. P. Jahnke (General Electric Company, Cincinnati, Ohio)

2. The Application of Titanium Alloys into the Olympus 593 Engine for the Concorde SST, A. H. Meleka, (Rolls-Royce, Filton, Bristol, Eng.)

3. Titanium Metal Fabrications in Aero Engines, A. Dix and R. Parkin (Rolls Royce Ltd., Loughborough, Leics., Eng.)

4. Titanium Applications for Supersonic Airplanes, Roger V. Carter (The Boeing Company, Seattle, Washington)

5. Future Possibilities for Titanium in Primary Aircraft Structures, A. J. Chivers (British Aircraft Corp., Weybridge, Surrey, Eng.)

6. Marine Applications of Titanium, W. L. Williams (Naval Ship R & D Center, Annapolis, Maryland)

7. Titanium Applications - U.S. Army, E. N. Kinas (Army Materials and Mechanics Research Center, Watertown, Mass.)

8. Titanium in the Process Industries Today, A. O. Freund (I.M.I., Ltd., Birmingham, Eng.)

9. Design and Fabrication of Titanium Alloy Pressure Vessels, B. V. Whiteson

10. Titanium Alloy Pressure Vessels in the Manned Spacecraft Program, Robert E. Johnson (National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas)

11. Texture Strengthening of Heat Treatable Alpha-Beta Titanium Alloys for Rocket Motor Case Application, J. M. Fitzpatrick, F. A. Crossley, R. E. Lewis and E. M. Schneider

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13. ABSTRACT

The International Conference on Titanium was held in London, 21-24 May 1968. About 120 papers were presented covering all aspects of the physical metallurgy of titanium and its alloys. The information developed in the past ten years has increased our understanding of titanium tremendously; several serious problems remain, notably in stress-corrosion cracking and welding.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Titanium Physical metallurgy Alloying Forging Heat Treatment Stress-corrosion Welding Fatigue Plating Oxidation Thermodynamics Electron Microscopy X-rays Creep						

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